

Retardation of Discoloration in Barley Flour Gel and Dough

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ABSTRACT

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Dark discoloration negatively influences the aesthetic properties of barley-based food products. The effects of abrasion and heat treatment of grains, exclusion of oxygen, and the use of antibrowning agents on the retardation of darkening in barley flour gel or dough were determined in four types of barley, including hulled proanthocyanidin-containing and hulled proanthocyanidin-free, hullless regular, and hullless waxy barley. Abrasion by >30% in hulled barley and by >15% in hullless barley significantly increased the brightness (L^*) of barley flour dough by 0.1–7.1. Steam heating of abraded grains also significantly increased the L^* of barley flour gels by 1.8–3.4. Ascorbic acid at 1,500 ppm was most

effective for retarding discoloration of barley flour dough, followed by 50 ppm of 4-hexylresorcinol, which is an enzyme competitive inhibitor. The discoloration of barley flour dough was also effectively reduced by storing the dough sheets at 4°C under nitrogen gas to exclude oxygen or under anaerobic conditions at 20°C. Discoloration of barley-based food products may be effectively controlled by selecting genotypes with low discoloration development such as proanthocyanidin-free genotypes, by lowering total polyphenol content or polyphenol oxidase (PPO) activity through abrasion, by heat treatment, by exclusion of oxygen, and by the use of enzyme inhibitors.

A small portion ($\approx 2\%$) of the U.S. barley crop is milled and pearled for food uses. However, with increasing awareness of the benefits of a healthy diet, barley consumption may increase. Progress in human nutrition research has established that the level of nutritional quality of barley-based products can be considered equal to that of oat products. Barley, like oats, is a source of dietary fiber, including β -glucans, which have cholesterol-lowering properties. Efforts are being made to increase the utilization of barley in traditional and new food products (Newman et al 1989; Oakenfull 1996; Jadhav et al 1998). An aspect that needs to be improved in barley processing is the dark appearance of barley food products. Discoloration in barley can occur by autooxidation of polyphenols in the presence of oxygen or by oxidation of polyphenols catalyzed by polyphenol oxidase (PPO) or metals. The substrates for PPO are oxygen and phenols. These phenolic compounds are hydroxylated in the *o*-position adjacent to an existing $-\text{OH}$ group, further oxidized to *o*-benzoquinones, and then by nonenzymatic reactions formed to melanins (brown pigments). *o*-Benzoquinones can react with nucleophiles such as amino groups of proteins. The *o*-benzoquinones can also react covalently with other phenolic compounds to give intensely colored products (Whitaker and Lee 1995).

Phenolic compounds in barley, including proanthocyanidins, are mainly located in the outer layers of grain (Outtrup 1981; McMurry et al 1983; Aastrup et al 1984). Abrasion removes the outer layers of the grain, thereby decreasing the polyphenol content of the kernel. PPO-catalyzed discoloration can be prevented by heat-inactivation of the enzyme (Vadlamani and Seib 1996). Lowering the temperature below the optimum can also be used to reduce enzyme activity (Ashie et al 1996). In addition, because oxygen is required for PPO activity, excluding oxygen from the product can inhibit enzymatic browning. Discoloration of oriental noodle dough was effectively controlled by using ascorbic acid alone or combined with storage under vacuum (Baik et al 1995).

Use of chemical agents is a common practice to prevent discoloration in food products. However, their use is limited because of concerns for human health or overall food quality (McEvily et al 1992). Chemical agents can be classified according to their primary mode of action. Ascorbic acid and sulfites are reducing agents that reduce quinones back to the original colorless phenols,

or that react irreversibly with quinones to form stable colorless products (McEvily et al 1992; Ashie et al 1996). Ethylene diamine tetra acetic acid (EDTA) is a chelating agent that chelates the copper prosthetic group of PPO or reduces the level of copper available for incorporation into the holoenzyme (McEvily et al 1992). 4-Hexylresorcinol is a competitive inhibitor of PPO that has a molecular structure similar to that of the enzyme substrate and thus competes for the active site of the enzyme. 4-Hexylresorcinol has been used to prevent browning in shrimp and in fruits and vegetables (McEvily et al 1992; Vámos-Vigyázó 1995; Ashie et al 1996). Benzoyl peroxide is a bleaching agent that bleaches out pigments such as xanthophylls (Melland et al 1984).

Because discoloration of food products occurs through chemical or enzymatic oxidation reactions, elimination or inactivation of the enzyme and substrate involved, limiting the oxygen availability by applying vacuum or replacing oxygen by nitrogen, as well as storing food products at low temperature, may also be effective in controlling undesirable color development.

In this study, abrasion, heat treatment, use of chemical agents, removal of oxygen, and low storage temperatures were independently evaluated as means of prevention or retardation of discoloration in barley.

MATERIALS AND METHODS

Materials

Barley grains were abraded with a tangential abrasive dehulling device (TADD, Venables Machine Works, Ltd., Saskatoon, Canada). For the abrasion experiment, six barley genotypes grown in Pullman, WA, in 2000 were used: Harrington and Steptoe (hulled proanthocyanidin-containing barley); CA803803 and WA13217-97 (hulled proanthocyanidin-free barley); and hullless, proanthocyanidin-containing barleys Bear (regular starch) and CDC Candle (waxy starch).

For heat treatment, use of chemical agents and oxygen-exclusion experiments, barley genotypes Harrington, Radiant (a hulled proanthocyanidin-free barley), Bear, and CDC Candle, grown in Pullman, WA, in 2001, were used. Outer layers of these barley grains were removed at 15 and 30% of the kernels by weight for hullless and hulled barley, respectively.

Abrasion

The outer layers of the barley grains were removed by abrasion at 20, 30, and 40% by weight in hulled barley and at 5, 15, and 25% in hullless barley. Nonabraded and abraded kernels were ground with a cyclone sample mill (Udy Corp., Fort Collins, CO) fitted with a 0.5-mm opening and subjected to chemical composition analysis.

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Chemical Analysis

Moisture content of barley flours was determined according to Approved Method 44-15A (AACC International 2000). Protein ($N \times 6.25$) was determined using a nitrogen analyzer (Leco Corporation, St. Joseph, MI) according to AACC Approved Method 46-30. AACC Approved Method 08-01 was used to determine ash content. Copper and iron contents were determined as follows: flour of abraded barley (1 g) was dry-combusted for 16 hr at 580°C, digested for 30 min in 2 mL of concentrated HCl, diluted to 25 mL with distilled water, and analyzed with an atomic absorption spectrophotometer (model 2380, PerkinElmer, Norwalk, CT) (Anonymous 1992). All analyses were performed at least in duplicate, and mean results of all analyses were reported on a moisture-free basis.

Total polyphenol content and PPO activity of the barley were determined spectrophotometrically according to the procedure described in detail in Quinde et al (2004). Briefly, polyphenols were extracted from barley flour with 30% (v/v) dimethylformamide. An aliquot of the extract was mixed with ammonia, 4-aminoantipyrine, and potassium ferricyanide solutions. The absorbance of the reaction mixture was read at 505 nm. The total polyphenol content was determined in duplicate and was expressed as gallic acid (%). Barley PPO was extracted with 50 mM potassium phosphate buffer at pH 6.5. After centrifugation, the clear supernatant was added into a cuvette containing 10 mM L-dopa. The change of absorbance per minute was measured at 480 nm over a 5-min period at 37°C. One unit was defined as the activity of the enzyme causing a change in absorbance of 0.001/min. PPO activity determination of barley flour was performed in triplicate and expressed as units per gram of flour.

Color Evaluations

The discoloration potential of abraded barley was evaluated through the brightness (L^*) of gels and dough sheets. Brightness was measured using a spectrophotometer (CM-2002, Minolta Camera Co., Chuo-Ku, Osaka, Japan) and expressed using the CIE-Lab L^* . The higher the L^* , the brighter the gels or dough sheets.

Gels were prepared from barley flour (10 g, 14% moisture basis) dispersed in water (90 mL). The slurry was heated and boiled for 5 min. After cooking, the hot paste was poured into a petri dish (clear polystyrene, 35 × 10 mm), cooled for 30 min at $20 \pm 2^\circ\text{C}$, covered with a lid, and inverted. Color of the resulting gel was measured through the inverted petri dish on duplicate samples.

Dough sheets were prepared by mixing flour (10 g, 14% moisture basis) with water (6.4 mL) in a 10-g mixograph (National Mfg., Lincoln, NE) for 1 min and sheeting on a cookie sheet to a thickness of 5 mm using a rolling pin. Dough sheets were placed in clear polyethylene plastic bags and kept at $20 \pm 2^\circ\text{C}$, unless otherwise specified. Color was measured through the plastic bag on duplicate samples.

Heat Treatment

A previous study on wheat PPO inactivation reported an optimum heat treatment of 8 min at 100°C on tempered wheat kernels (Vadlamani and Seib 1996). For this study on barley, PPO was inactivated by both soaking and steaming and by steaming only. For soaking and steaming, abraded barley kernels (50 g) were soaked in water for 2, 4, 6, and 12 hr, placed in cheesecloth bags, and then steamed for 8 min at 100°C in a steamer (Ultra Steam,

TABLE I
Effect of Abrasion on Chemical Composition of Barley Flours and Brightness (L^*) of Barley Gels and Doughs After 24 hr of Storage^{a,b}

Genotype	Abrasion (%)	Protein (%)	Ash (%)	Cu (mg/100 g)	Fe (mg/100 g)	Total Polyphenol (gallic acid %)	PPO (unit/g)	Gel (L^*)	Dough (L^*)
Hulled									
Proanthocyanidin-containing									
Harrington	0	10.9a	2.28a	nd	nd	0.38a	94.6a	nd	nd
	20	10.8a	1.22b	0.36a	2.92a	0.24b	76.5b	54.5b	64.1c
	30	10.6b	0.91c	0.37a	3.18a	0.16c	71.0c	54.8b	69.5b
	40	9.9c	0.75d	0.36a	2.55a	0.11d	65.1d	55.6a	72.5a
Stephoe	0	10.9a	2.34a	nd	nd	0.47a	95.8a	nd	nd
	20	10.8a	1.22b	0.28a	3.02a	0.28b	72.6b	54.6b	62.6c
	30	8.9b	0.96c	0.31a	1.98b	0.18c	66.3c	55.3ab	67.8b
	40	8.9b	0.75d	0.06b	0.86c	0.11d	64.4d	56.9a	72.7a
Proanthocyanidin-free									
CA803803	0	11.2a	2.26a	nd	nd	0.10a	171.4a	nd	nd
	20	11.4a	1.06b	0.28b	2.67a	0.04b	123.4b	58.1a	71.7b
	30	9.5b	0.88c	0.43a	2.84a	0.03c	116.5c	58.1a	76.5a
	40	9.3c	0.58d	0.25b	1.32b	0.02d	107.9d	58.6a	76.6a
WA13217-97	0	11.9a	2.27a	nd	nd	0.13a	162.7a	nd	nd
	20	11.6a	1.28b	0.33a	2.08a	0.09b	95.6b	59.0a	68.6c
	30	10.1b	0.98c	0.15b	2.56a	0.03c	88.0bc	59.5a	72.2b
	40	9.8c	0.75d	0.17b	1.00b	0.02d	83.9c	59.6a	76.0a
Hullless									
Regular									
Bear	0	13.7a	1.58a	nd	nd	0.42a	96.1a	nd	nd
	5	13.2b	1.45b	0.41a	4.85a	0.34b	89.2b	52.3b	56.6c
	15	11.3c	0.99c	0.30b	3.12b	0.22c	78.4c	53.4ab	62.8b
	25	10.8d	0.83d	0.42a	3.25b	0.13d	70.5d	54.7a	69.9a
Waxy									
CDC Candle	0	14.2a	1.63a	nd	nd	0.44a	113.8a	nd	nd
	5	13.5b	1.36b	0.33a	4.57a	0.31b	94.3b	52.5a	54.0c
	15	11.7c	0.99c	0.17a	2.88b	0.19c	79.9c	53.5a	60.6b
	25	10.9d	0.64d	0.23a	1.83c	0.11d	77.1c	53.2a	67.7a

^a Mean values followed by the same letter within each cultivar are not significantly different ($P < 0.05$).

^b Not determined (nd).

Market Forget, Crescent Machine Works, Spokane, WA). After heat treatment, the grains were immediately placed in an ice water bath for 2 min, drained, and freeze-dried. For the abraded kernels steamed for 8 min at 100°C without soaking, the grains in cheese-cloth bags were immediately cooled to ≈2°C by placing them between cold plates to avoid soaking in water and then freeze-dried. The lyophilized grains were ground into flour. Steaming partially gelatinizes the starch and increases the amount of water needed for making flour dough of heat-treated grains. Accordingly, only gels were prepared from barley flours of both control and steamed grains for the evaluation of brightness (L^*). Gels were prepared as described previously and subjected to color measurement in duplicate samples.

Chemical Agents

Effectiveness of chemical agents on the retardation of discoloration in barley-based foods was evaluated in dough sheets. Dough sheets were prepared in duplicate as described above, and brightness (L^*) was measured immediately after preparation (0 hr) and at 1, 2, 4, 6, 12, 24, and 48 hr after preparation. Ascorbic acid (1.5 mg/g of barley flour), sodium sulfite (0.1 mg/g of barley flour), and EDTA (0.05 mg/g of barley flour) were dissolved in water and 4-hexylresorcinol (0.05 mg/g of barley flour) in 95% ethanol. These antibrowning agents were incorporated into the dough in 1-mL aliquots during mixing. Water-soluble chemical agents were added after adding 5.4 mL of water, while 4-hexylresorcinol was added after adding 6.4 mL of water. Benzoyl peroxide (0.04 mg/g of barley flour) was directly added into the flour and aged for four days (Melland et al 1984). The treated flour was then used to prepare the dough sheets. The amounts of these chemical agents represented the highest amount allowed by the U.S. Food and Drug Administration. 4-Hexylresorcinol is a GRAS food additive, but is not approved for cereal products. Chemical reagents were purchased from Sigma-Aldrich (St. Louis, MO).

Storage Conditions

The effect of temperature and removal of oxygen on discoloration potential of barley was evaluated in dough sheets. Dough sheets were prepared in duplicate as described above and placed in plastic bags of low oxygen permeability (PET/LLDPE, Kapak Corp., Minneapolis, MN). Vacuum was applied, and nitrogen or air was injected into the plastic bags using an Ultravac (Koch Equipment Group, Kansas City, MO). The dough sheets were then stored at $4 \pm 0.5^\circ\text{C}$ or $20 \pm 2^\circ\text{C}$. Brightness (L^*) was measured immediately after preparation (0 hr), and at 1, 2, 4, 6, 12, 24, and 48 hr after preparation. For comparison purposes, dough sheets were also stored in an anaerobic gas pack system (BBL, BD Biosciences, Sparks, MD) for 48 hr. Measurements of color were taken after preparation of dough sheets (0 hr) and after 48 hr of storage. The BBL gas pack system consisted of a 2.5-L

TABLE II
Effect of Soaking and Steaming of Barley Grains on Brightness (L^*) of Barley Gels

Treatment	Time (hr)	Cultivar ^a			
		Harrington	Radiant	Bear	CDC Candle
Control ^b	—	55.9c	59.0de	54.3bc	53.3e
Soaking only	2	55.2de	58.9e	54.1c	52.5fg
	4	55.8cd	59.5d	54.7b	52.6f
	6	55.3c-e	59.5d	54.5bc	52.1gh
	12	55.1e	59.4de	54.0c	51.9h
Soaking + steaming	2	57.9b	60.3c	57.5a	56.3b
	4	58.1b	61.2ab	57.7a	56.1b
	6	58.3b	61.4a	57.7a	55.7c
	12	58.1b	61.1ab	57.2a	55.2d
Steaming only	—	59.2a	60.8b	57.6a	56.7a

^a Mean values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b Barley flour gels prepared from grains that were not soaked or steamed.

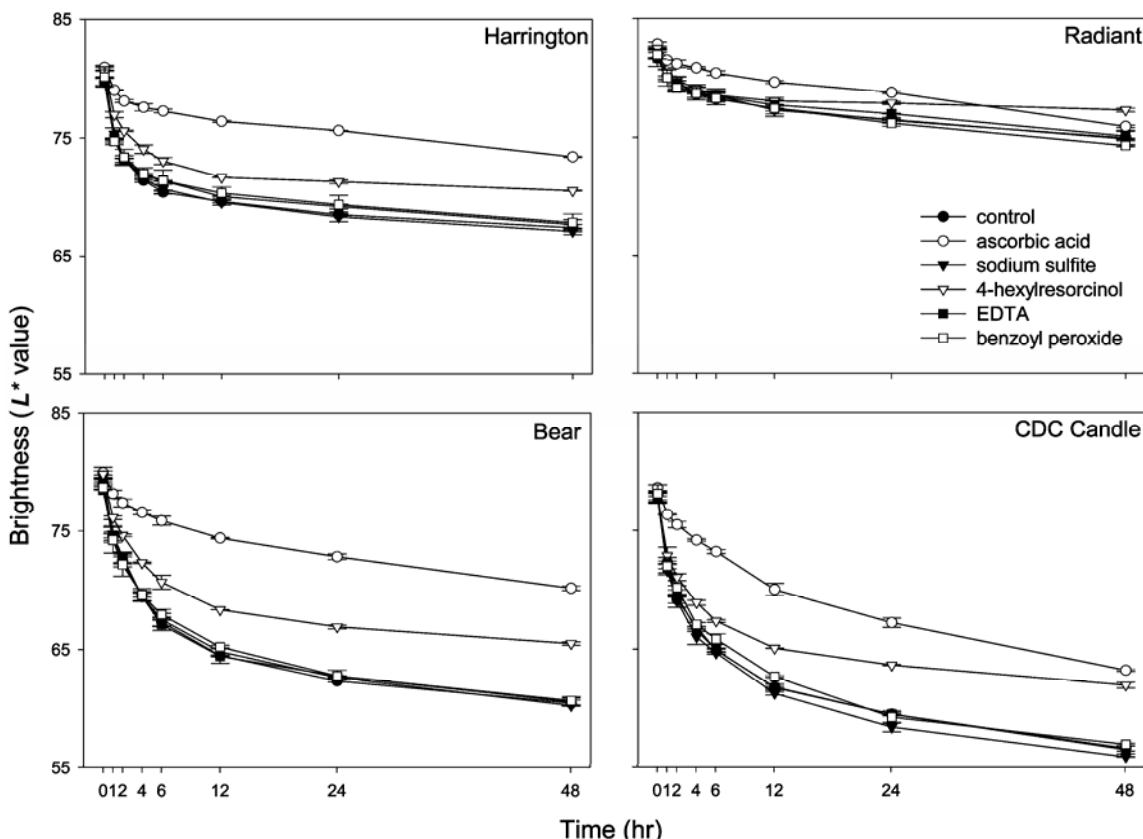


Fig. 1. Effect of antibrowning agents on brightness of barley dough from cultivars Harrington, Radiant, Bear, and CDC Candle. Least significant differences ($\alpha = 0.05$) for L^* at 24 hr were Harrington (0.9), Radiant (0.4), Bear (0.6), and CDC Candle (0.8).

vacuum container, a chemical mix that generates anaerobic conditions in the container (AnaeroGen, AN25, Oxoid Ltd., Basingstoke, Hampshire, England), and a disposable anaerobic indicator. According to specifications of the manufacturer, elimination of oxygen is $\approx 99\%$ of the initial content.

Statistical Analysis

Chemical analyses of abraded grains were made at least in duplicate. The experiments of using chemical agents, heat treatments, and storage conditions for the retardation of discoloration were replicated twice. Dough and gel color was measured in triplicate and averaged. Statistical analysis of data was performed using statistical software (SAS Institute, Cary, NC) with a generalized linear model procedure, Fisher's least significant difference (LSD), and Pearson's correlation coefficient. Differences were considered significant at $P < 0.05$, unless otherwise specified.

RESULTS AND DISCUSSION

Abrasion

Abrasion significantly decreased protein, ash, total polyphenol content, and PPO activity in all of the genotypes (Table I). Changes in copper and iron content were not always evident but, in general, a decreasing trend due to abrasion was observed. CA803803 had significantly higher PPO activity at all levels of abrasion than the other genotypes. A large improvement in brightness of gels and dough by abrasion was observed in hulless and hulled proanthocyanidin-containing genotypes. While hulled proanthocyanidin-free genotypes produced much higher L^* of gels and doughs, the increases in L^* of gels by abrasion were much smaller compared with the increases observed in hulled proanthocyanidin-containing and hulless genotypes (Table I). Removal of the outer layers from 30–40% of the kernel by weight increased the brightness of dough sheets by 0.1–3.8 in hulled proanthocyanidin-free genotypes and by 3.0–4.9 in hulled proanthocyanidin-containing genotypes. For regular and waxy hulless genotypes, abrading 15–25% increased brightness of dough sheets by 7.1. Significant increases in brightness were more evident in dough sheets than in gels, probably due to the lower barley flour concentration of the gel compared with dough sheets and the heat applied during the preparation of the gel. Yeung and Vasanthan (2001) reported significant improvement of gel brightness by abrasion at 32% in hulless barley. Although similar improvement of brightness could be obtained by combining genotype and degree of abrasion, proanthocyanidin-free genotypes at all levels of abrasion offer an advantage over proanthocyanidin-containing genotypes. Pearson correlation analysis among genotypes at different percentages of abrasion ($n = 18$) indicated that protein ($r = -0.82$, $P < 0.0001$), ash ($r = -0.76$, $P = 0.0003$), iron ($r = -0.76$, $P = 0.0003$), and total polyphenol content ($r = -0.93$, $P < 0.0001$) were significantly related to brightness of dough sheets. Hulless genotypes were generally higher in protein, ash,

Cu, Fe, and total polyphenol content of abraded grains than hulled genotypes. Proanthocyanidin-free genotypes were highest in PPO activity.

Heat Treatment

Table II shows the effect of soaking and heating treatment on the brightness of gels. Soaking alone did not significantly affect the brightness of gels prepared from Harrington, Bear, and Radiant. For CDC Candle, extended soaking negatively affected the color of the gels, potentially due to the further release of phenolic compounds and their oxidation in gel. Soaking and subsequent steaming had variable effects on brightness of gels among barley cultivars. For Radiant, soaking grains more than 2 hr and steaming increased the brightness of gels. With Harrington and Bear, increased soaking time of grains with subsequent steaming had no significant effect on brightness of gels, whereas for CDC Candle, as soaking time of grains increased, the brightness of gels decreased. Compared with the control, soaking and subsequent steaming together improved the brightness of gels. Steaming barley grains without soaking increased the brightness of gels (L^*) compared with the control by 1.8 in Radiant, by 3.3 in Harrington and Bear, and by 3.4 in CDC Candle. For Harrington and CDC Candle, steaming alone was more effective for improving gel brightness than soaking plus steaming, while for Radiant and Bear, steaming alone had similar effects on brightness than soaking plus steaming.

Steaming alone significantly decreased the PPO activity of all barley cultivars tested. Harrington, Radiant, Bear, and CDC Candle lost 57, 86, 83, and 53% of initial PPO activities, respectively. The residual PPO activity in Harrington was 26 units/g, in Radiant 17 units/g, in Bear 14 units/g, and in CDC Candle 31 units/g. This result suggests that heat treatment can be effectively used to inactivate PPO and thus reduce the discoloration potential of barley-based products. However, heat treatment may also change the functional properties of barley through starch gelatinization and protein denaturation, as previously reported by Fasina et al (1999).

Chemical Agents

The effect of different chemical agents on retarding the discoloration of flour dough was determined by the brightness (L^*) of dough sheets during storage (Fig. 1) and by calculating the decreases (ΔL^*) at 24 hr (Table III). Among chemical agents, the use of ascorbic acid resulted in significantly higher brightness of dough sheets at 24 hr for all four cultivars tested. Similar effects of ascorbic acid on retarding discoloration of oriental noodle doughs prepared with wheat flour were reported by Baik et al (1995). The second most effective antibrowning agent was 4-hexylresorcinol, a competitive inhibitor of PPO. Dough sheets prepared from Harrington, Bear, and CDC Candle and treated with 4-hexylresorcinol had significantly higher brightness (L^*) at 24 hr and smaller ΔL^* (Fig. 1, Table III) than the dough sheets

TABLE III
Decreases in Brightness (ΔL^*)^a at 24 hr After Storage at 20°C of Barley Dough Sheets Treated with Antibrowning Agents

Treatment	Cultivar ^b			
	Harrington	Radiant	Bear	CDC Candle
Control ^c	11.2b	5.3ab	16.7ab	18.5a
Ascorbic acid (1,500 ppm)	5.4e	4.1a	7.1d	11.4c
4-Hexylresorcinol (50 ppm)	9.2d	4.6bc	12.9c	14.2b
Sodium bisulfite (100 ppm)	12.1a	5.9a	16.9a	19.4a
EDTA (50 ppm)	10.6c	4.7bc	15.8b	18.3a
Benzoyl peroxide (40 ppm)	10.9bc	5.8a	15.9b	18.8a

^a Calculated as L^* at 0 hr — L^* at 24 hr of storage.

^b Mean values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^c Barley flour doughs prepared with water only.

TABLE IV
Decreases in Brightness (ΔL^*)^a of Barley Dough Sheets After 48 hr of Storage at Different Conditions

Treatment	Cultivar ^b			
	Harrington	Radiant	Bear	CDC Candle
At 20°C				
Air (control)	11.7a	7.7a	15.5a	18.4a
Nitrogen	8.1b	3.5b	12.6b	15.9b
Anaerobic	4.9c	2.3c	8.2c	10.9c
At 4°C				
Air	7.0b	4.3b	8.8c	11.6c
Nitrogen	4.4c	2.0c	6.7c	8.7d

^a Calculated as L^* at 0 hr — L^* at 48 hr of storage.

^b Mean values followed by the same letter in the same column are not significantly different ($P < 0.05$).

from the control. Weemaes et al (1999) reported that 4-hexylresorcinol effectively inhibited mushroom PPO activity. However, 4-hexylresorcinol was neither a good inhibitor of grape PPO (Martinez and Whitaker 1995) nor effective in improving the brightness of wheat noodle dough (Baik et al 1995). Sodium sulfite, EDTA, and benzoyl peroxide were not effective in reducing discoloration of barley dough sheets. The lack of effectiveness of these antibrowning agents may be partially explained by the complex nature of barley flour dough discoloration, which may not involve the reactions controllable using sodium sulfite, EDTA and benzoyl peroxide. The concentration of those agents used may not be high enough to effectively stop discoloration of barley flour dough. Ashie et al (1996) indicated that the effective sulfite concentration for preventing discoloration primarily depends on the nature of the available substrate, and that more complex phenolic compounds would require higher sulfite concentrations. For genotypes, the effectiveness of the antibrowning agents appeared smaller for Radiant than for the other cultivars, mainly because Radiant, a proanthocyanidin-free barley, exhibited little decrease in brightness of dough sheet during storage, even without the use of antibrowning agents (Quinde et al 2004). The results of chemical antibrowning agents indicate that by preventing accumulation and further polymerization of oxidized phenolic compounds, as well as by inhibiting the enzymatic oxidation of phenolic compounds by PPO, the discoloration potential of barley may be effectively controlled.

Low Temperature Storage and Removal of Oxygen

Figure 2 shows the changes in brightness (L^*) of dough sheets stored at different combinations of temperature and atmospheric conditions. Similar to chemical agents, for all storage conditions, Radiant (hulled proanthocyanidin-free cultivar) exhibited little decrease in brightness (L^*) compared with Harrington, Bear, and

CDC Candle (proanthocyanidin-containing cultivars). Use of nitrogen was as effective at 4°C as at 20°C during the first 1–2 hr of storage, but from 2 to 12 hr, the use of nitrogen was much more effective at 4°C than at 20°C. Lowering the temperature may affect the kinetics of PPO activity (Ashie et al 1996) as well as the rate of diffusion of gases (oxygen) within and through the packaging, thus reducing discoloration. We observed that the low oxygen availability for oxidative reactions resulted in less discoloration of dough sheets for all cultivars (Table IV). Anaerobic conditions significantly reduced the discoloration of dough sheets, but were not significantly different from the treatment combination of 4°C and nitrogen. Removal of oxygen had an effect equal to storage at 4°C and nitrogen atmosphere for all cultivars except CDC Candle. Both low temperature and the elimination of oxygen effectively retarded the discoloration of dough sheets of the cultivars evaluated. This result suggests that by limiting the conditions for PPO oxidation of phenolic compounds, discoloration potential of barley may be reduced.

CONCLUSIONS

Hulled proanthocyanidin-free genotypes exhibited the lowest discoloration of barley flour dough and gel. For all barley types tested, lowering total polyphenol content and PPO activity by abrasion reduced the discoloration potential of barley flour dough. Heat treatment also effectively reduced PPO activity of abraded kernels. A drawback of heat treatment such as steaming is its effect on the functional properties of the barley flour. Chemical agents such as ascorbic acid and 4-hexylresorcinol retard the discoloration potential of barley. Removal of oxygen and low temperature can also be used to reduce the extent of discoloration of barley dough sheets.

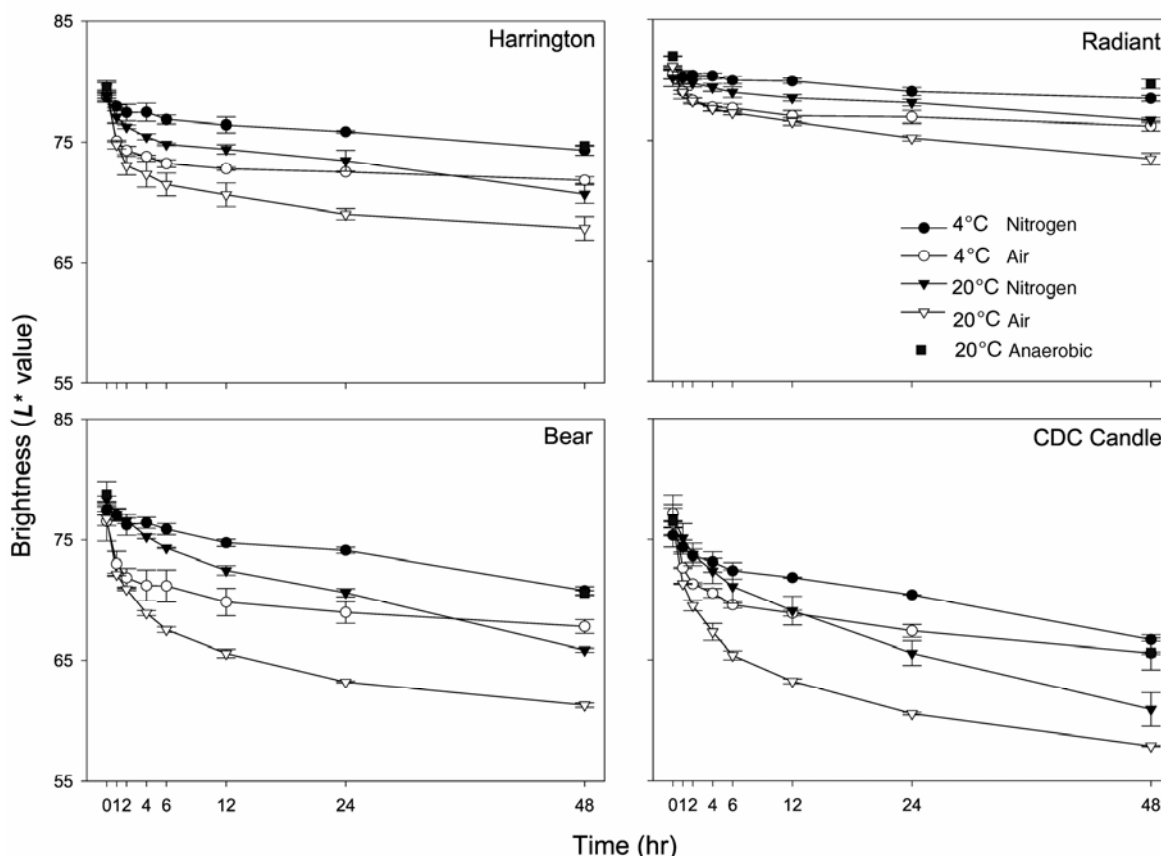


Fig. 2. Effect of storage conditions on brightness of barley dough from cultivars Harrington, Radiant, Bear, and CDC Candle. Least significant differences ($\alpha = 0.05$) for L^* at 48 hr: Harrington (1.5), Radiant (0.9), Bear (0.9), and CDC Candle (2.3).

ACKNOWLEDGMENTS

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